Acronym: MDCA-FLEX

Title: Multi-User Droplet Combustion Apparatus - Flame Extinguishment Experiment

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Sponsoring Agency: National Aeronautics and Space Administration (NASA)

Increment(s) Assigned: 18, 19, 20

Brief Research Summary (PAO): Multi-User Droplet Combustion Apparatus Flame Extinguishment Experiment (MDCA-FLEX) will assess the effectiveness of fire suppressants in microgravity and quantify the effect of different possible crew exploration atmospheres on fire suppression. The goal of this research is to provide definition and direction for large scale fire suppression tests and selection of the fire suppressant for next generation crew exploration vehicles.

Research Summary:

- The combustion and extinction characteristics of liquid fuel droplets in microgravity are determined by the complex interaction of fuel vapor and oxidizer transport, fuel vaporization, conductive, convective and radiative heat loss and chemical kinetics. All of these phenomena are critical in real fire scenarios and thus in understanding the complex issues involved in the design of an effective fire suppression system.

- The simplicity of the droplet geometry lends itself to detailed theoretical and numerical studies. By comparing the results of the experiments to these detailed treatments it is possible to develop validated chemical kinetic and heat and mass transport mechanisms for liquid fuels. From these fundamental mechanisms it becomes possible to develop validated, predictive, reduced-scale mechanisms that are appropriate for modeling real fire suppression scenarios aboard future spacecraft.

- The Multi-User Droplet Combustion Apparatus - Flame Extinguishment Experiment (MDCA-FLEX) investigation will yield both a quantitative measure of the effectiveness of various suppression agents and more importantly a set of predictive tools that will allow the effective, efficient design of future spacecraft fire suppression systems.

Detailed Research Description: Multi-User Droplet Combustion Apparatus - Flame Extinguishment Experiment (MDCA-FLEX) will map the flammability boundaries for liquid fuel combustion in reduced gravity to quantify the suppressant efficacy of various gaseous suppressants over the range of candidate

atmospheric pressures and oxygen concentrations. This investigation will develop predictive theoretical and numerical codes and chemical kinetic schemes to model flammability boundaries as a function effective gravitational acceleration on the unique ambient conditions encountered in space exploration applications.The development and validation of these models will require detailed spatially and temporally resolved measurements of droplet burning rate, flame extinction, flame radiation, soot concentration, soot temperature, etc. This investigation will also develop improved and validated reduced (simplified) theoretical and numerical sub-models of important physical processes (chemical kinetics, radiation, soot formation/destruction) that can be used in simulations of large scale, realistic fires.

The independent experiment variables analyzed by MDCA-FLEX are:

Oxygen Mole Fraction: The ambient oxygen mole fraction in a typical space environment can vary from high concentrations in EVA pre-breathing environments down to that typically found in air. At high oxygen concentrations, however, the chemical times are small enough (relative to the characteristic flow times) such that the droplets will burn to completion rather than exhibiting flame extinction. Therefore, it is also necessary to study low oxygen concentrations, down to the Limiting Oxygen Index (LOI). It is also important to determine the LOI in order to verify the chemical mechanisms. The oxygen mole fractions in the present study will vary from 0.10 to 0.50. The chamber must also be large enough such that there is no significant decrease in ambient oxygen mole fraction during an experiment (i.e. the droplet burns in an essentially constant ambient).

Diluent (non-suppressant): The ambient mixture will consist of oxygen mixed with a suppressant and the balance of an inert diluent gas. The diluent gas for these studies will be primarily nitrogen since that is the typical diluent on Earth and expected in space. There will be a small number of tests with a helium diluent gas. The reason is primarily for baseline comparisons with the Droplet Combustion Experiment, which used helium as the diluent gas and also to vary the physical properties of the diluent gas.

Suppressant Type: The tests will examine candidate gaseous suppressants that have widely varying physical, chemical and radiative properties. This will enable model and sub-model development and validation over a wide range of ambient conditions to improve the predictive capabilities of the models. The suppressants are carbon dioxide and helium. The expected concentrations range from 0.00 mole fraction to the limit where no flame can exist (0.70 expected for the least active suppressant).

Pressure: Ambient pressure does not significantly influence the droplet burning rate, but does influence chemistry at sufficiently low values. In addition, one strategy for extinguishing a fire is to isolate the habitat where it exists and vent the cabin to space. It is therefore beneficial to have verified suppressant data at low pressures. The pressure for the tests will range from 0.5 to 1.0 atm (standard atmosphere). As with the oxygen mole fraction, it is important that the test chamber be sufficiently large so that the pressure is essentially constant during an experiment (i.e. the droplet burns in a constant pressure ambient).

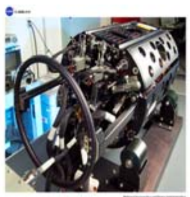
Fuel Type: The advantage of the droplet geometry is that the fuel is relatively simple and better characterized than typical fuels in fire safety studies (e.g. PMMA or paper). This is also a disadvantage since it does not represent a practical fuel. The study will use two typical hydrocarbon fuels, an alcohol, methanol (CH_3OH) and an alkane, heptane (C_7H_{16}). There is a relatively large experience base with these fuels. Methanol has a fuel-bound oxygen atom, and burns with a very dim blue flame (not much soot production) with a small standoff distance, so it has widely different radiative characteristics than heptane. Therefore, studying these two fuels gives a wide range of fire scenarios to verify model and sub-model performance over.

Droplet Diameter: The droplet is ignited in the flammable region and then burns in a constant oxygen mole fraction ambient until flame extinction. Under the assumption of quasisteady burning, the initial droplet size should not significantly influence the determination of the extinction droplet size. Transient influences, however, will be present, so some variation in initial droplet diameter is necessary to determine the deviation from quasi-steady behavior. The initial droplet size in the proposed study will vary between 2 and 5 mm.

Project Type: Payload

Images and Captions:


Burning droplet from the Droplet Combustion Experiment, image courtesy or Glenn Research Center.


NASA Image: C-2006-414: Flight Unit Multi-User droplet Combustion Apparatus (MDCA) Chamber Insert Assembly (CIA).


NASA Image: ISS018E010645 - Astronaut Michael Fincke, Expedition 18 commander, works on the Multi-User Droplet Combustion Apparatus (MDCA) Chamber Insert Assembly (CIA) in the Harmony node of the International Space Station.

Operations Location: ISS Inflight

Brief Research Operations:

- MDCA-FLEX will be setup and operated in the Combustion Integrated rack (CIR) on ISS.
- The investigation will generate droplets from methanol or heptane as required by the test point.
- The data will be recorded via video using the CIR optics bench.

Operational Requirements: The MDCA-FLEX investigation will be setup in the Combustion Integrated Rack (CIR). The CIR chamber will be filled with the appropriate atmosphere depending on the test point. A total of 196 test points are required for completion of MDCA-FLEX. Fuel will be dispensed followed by ignition. All activities will be captured in near real-time download with the CIR color camera video.

Operational Protocols: Following setup and initialization of the MDCA-FLEX investigation the chamber shall be filled with the appropriate atmosphere, which depending on the test point, will vary in pressure from 0.5 atm to 3.0 atm, will vary in oxygen concentration from 0.1 to 0.4 mole fraction, and will vary in suppressant concentration from 0 to 0.7 mole fraction. A settling time of approximately 2 minutes will elapse prior to initiating the test in order to ensure that the temperature and pressure of the chamber gases have stabilized. This settling time will be followed by the dispensing of a predetermined amount of fuel (based on the target droplet size) onto the support fiber. When sufficient fuel has been dispensed the

dispensing needles will be retracted and a dwell period of at least 10 seconds will be allowed for the droplet internal fluid motion induced by deployment to subside.

This will then be followed by initiating power to the igniter for a selectable amount of time ranging from 1 second to 5 seconds after which the igniter will be retracted from the field of view. If the flow field is to be generated by translating the droplet then droplet motion would commence at the same time that the igniter is retracted. A near real-time download of the color camera video will be required in order to verify successful droplet deployment, ignition, and overall progress of the experiment. Pressure and temperature data of the chamber environment will also be required in near real time.

At least 2 minutes must be allowed after filling chamber to ensure that the chamber gas temperature and pressure has stabilized. For droplet dwell time allow at least 10 seconds to ensure all droplet motion imparted by droplet deployment and needle retraction has subsided. Chamber purity for fuel vapor mole fraction of less than 0.005 in the atmosphere for tests without carbon dioxide and less than 0.02 mole fraction (each species) of carbon monoxide, carbon dioxide and other products.

Review Cycle Status: PI Reviewed

Category: Technology Development

Sub-Category: Spacecraft Systems

Space Applications: MDCA-FLEX will help us develop more efficient energy production and propulsion systems on Earth and in space.

Earth Applications: MDCA-FLEX will help in the understanding to deal better with combustion generated pollution, and address fire hazards associated with using liquid combustibles on Earth.

Manifest Status: New

Supporting Organization: Exploration Systems Mission Directorate (ESMD)

Previous Missions: The Fiber Supported Droplet Combustion Experiment, (FSDC), a predecessor to MDCA-FLEX was performed on STS-73 (October 20, 1995) and STS-83 (April 4, 1997). The Droplet Combustion Experiment (DCE), another predecessor was performed on STS-83 (April 4, 1997) and STS-94 (July 1, 1997). The fundamentals addressed by these experiments are essential to the fundamentals that impact fire sensing and suppression technologies applicable to space exploration environments.

Web Sites:
Space Flight Systems at GRC

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